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(54) **Shape sorting**

(57) In order to provide an accurate sort into many different classes, signals are generated (1, 2) representative e.g. of the maximum, minimum and mean of the blockiness and symmetry of objects, and e.g. the maximum and mean of the convex hull deviance of the objects. The signals, together with an edge-breakthrough count, are subjected (3) to a linear transformation to provide a normalised shape parameter which is assigned a value of e.g. 0 to 15, for each class being sorted, on the basis of the expected occurrence of the value of the parameter in that class. Each pair of normalised shape parameters so determined is used (4, 5) to derive a shape decision value from a table specific for that pair of secondary shape parameters. The shape class of the object is ascertained (7) on the basis of a majority vote for all the shape decision values. The tables may be "learnt" by the machine by feeding a statistically significant number of samples representative of a number of shape classes through the machine. The objects may be rough diamonds.

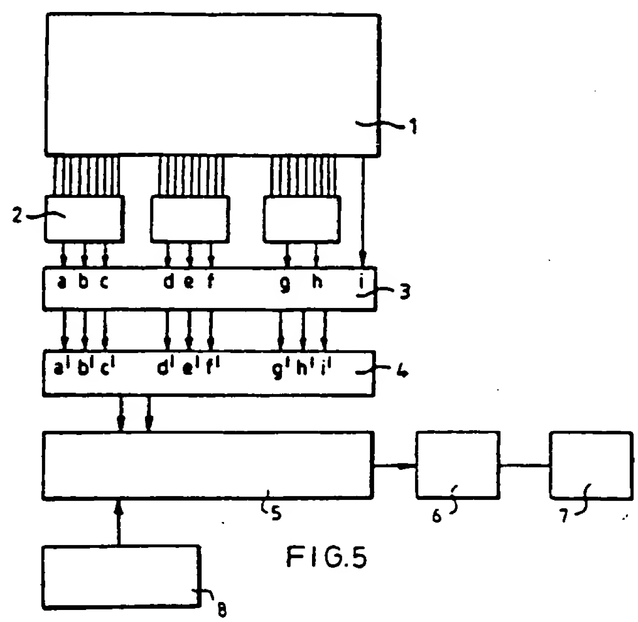
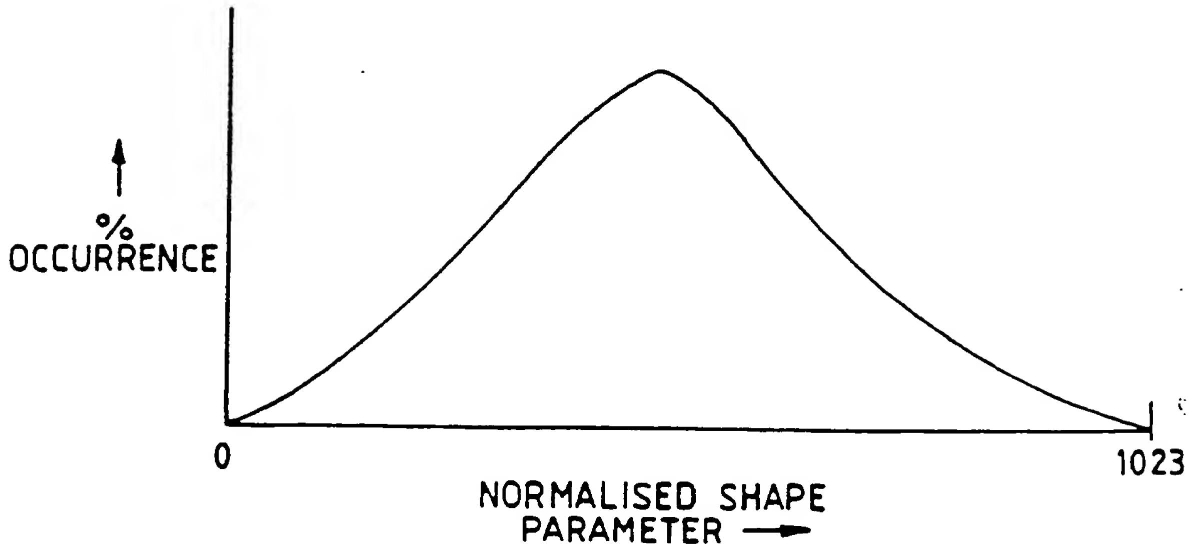


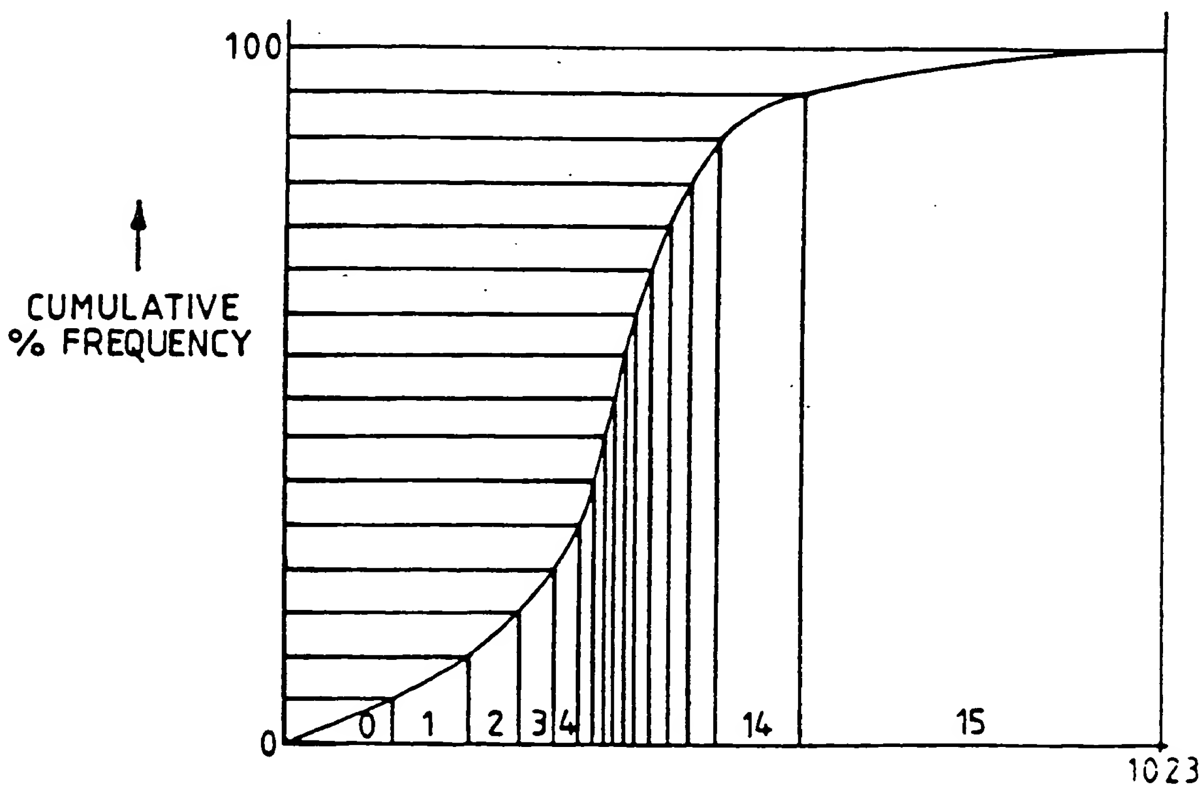
FIG.5

GB 2 246 230 A



%
OCCURRENCE
0
1023
NORMALISED SHAPE
PARAMETER

FIG.1



100
CUMULATIVE
% FREQUENCY
0
0
1
2
3
4
14
15
1023

FIG.2

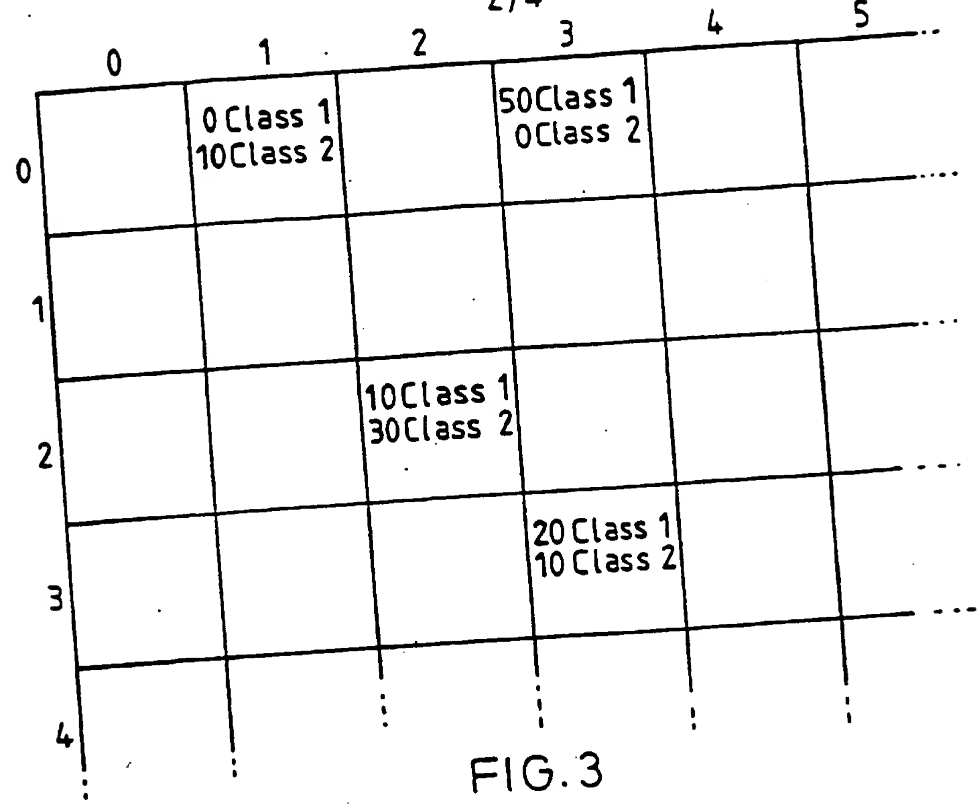

0
1
2
3
4
5
0
1
2
3
4
0 Class 1
10 Class 2
50 Class 1
0 Class 2
10 Class 1
30 Class 2
20 Class 1
10 Class 2

FIG. 3

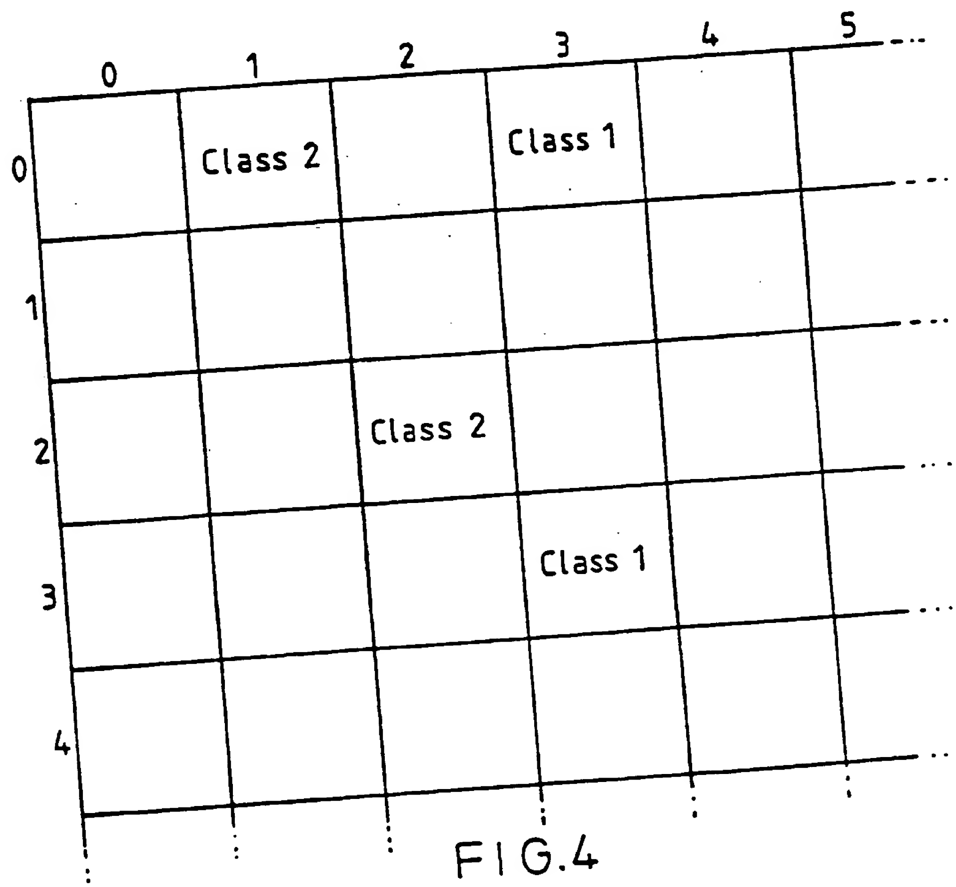

0
1
2
3
4
5
0
1
2
3
4
Class 2
Class 1
Class 2
Class 1

FIG. 4

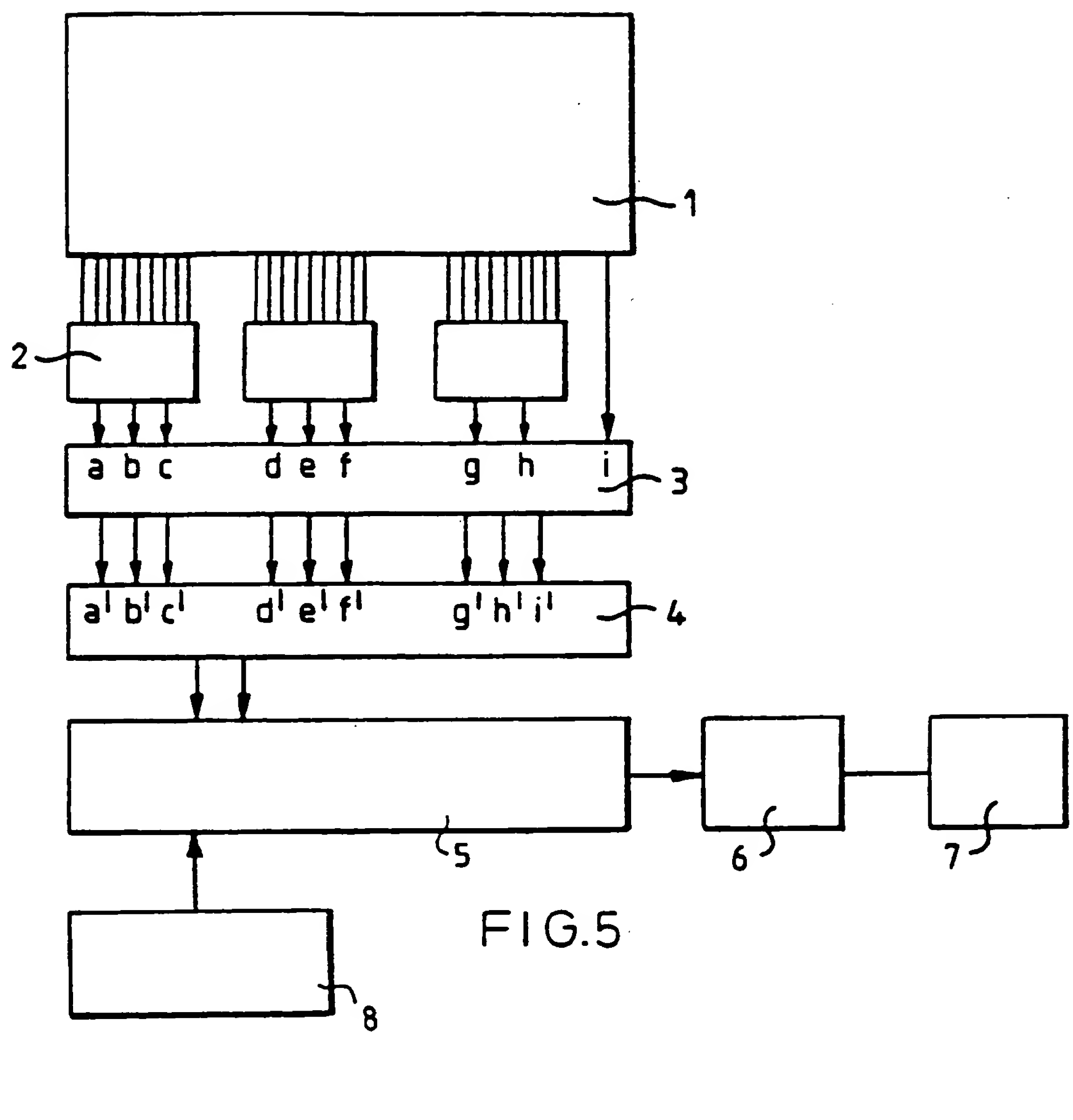
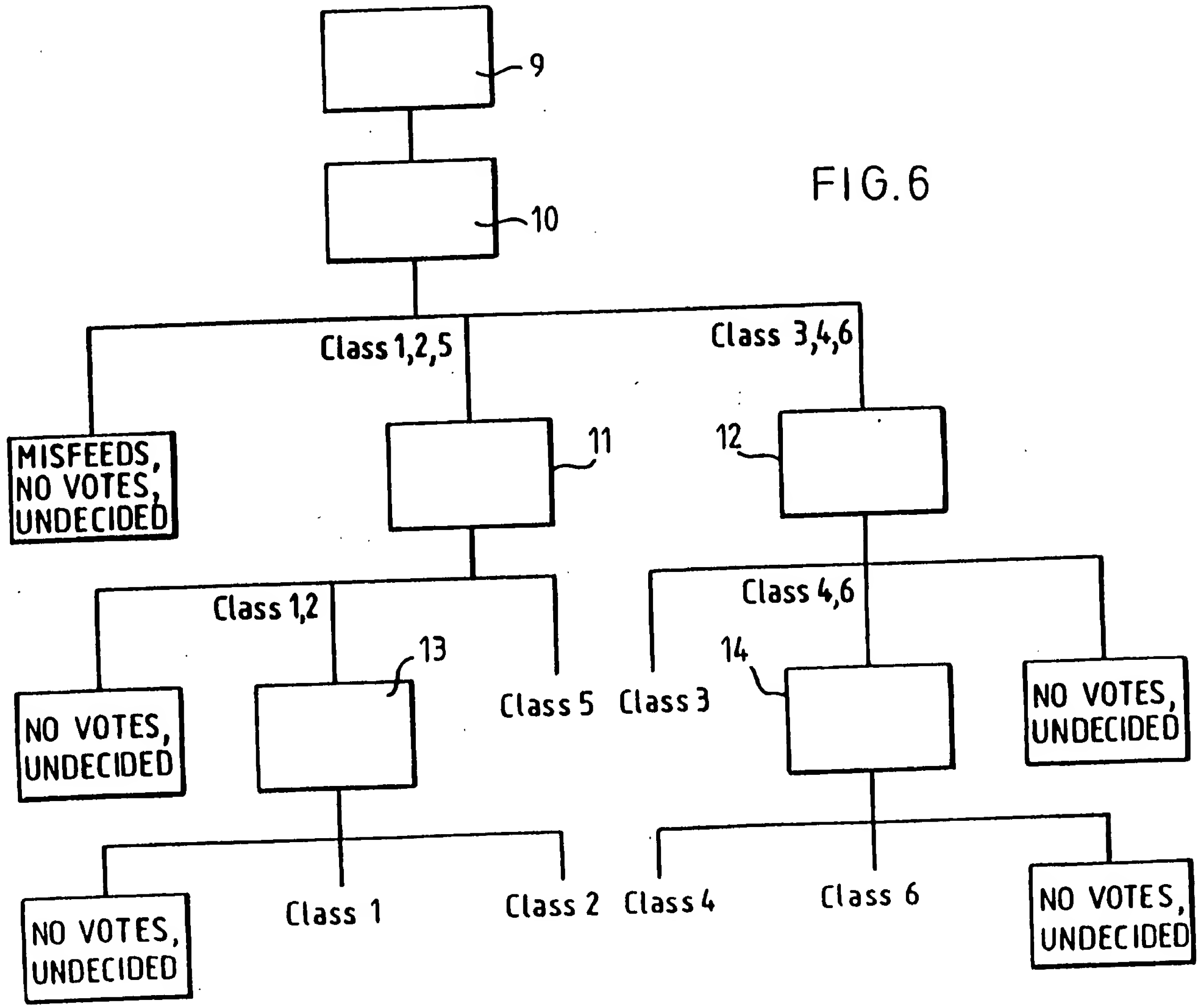


FIG.5

FIG.6


9
10
Class 1,2,5
Class 3,4,6
MISFEEDS, NO VOTES, UNDECIDED
11
12
Class 1,2
13
Class 5
Class 3
Class 4,6
14
NO VOTES, UNDECIDED
NO VOTES, UNDECIDED
NO VOTES, UNDECIDED
Class 1
Class 2
Class 4
Class 6
NO VOTES, UNDECIDED

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SHAPE SORTING

Background of the Invention

This invention relates to a method of ascertaining the classification of the shape of an object based upon deriving a set of values for features representative of the shape of the object.

For example the method may be used with apparatus described in GB-A-2184832. This discloses an apparatus having a viewing zone through which the object is fed. The object is lluminated whilst in the viewing zone and viewed by a number of fixed electronic viewers spaced around the viewing zone. The images of the object derived by the viewers are all derived at substantially the same time. The signals from each viewer comprise video pictures which are subsequently normalised (white made true white, black made true black) by selecting a voltage threshold between black and white, and digitised. Digital data for each viewer representive of the edges of the object is then derived by tracking all the points in the image where white (which in this case represents the background, as the objects are viewed

dark against a light field) goes to black or black goes to white. Basic shape parameters of the object are then derived for each viewer.

GB-A-2184832 also discloses a method of ascertaining the shape class of an object using the apparatus by processing the average values of the basic shape parameters for all the viewers using a decision tree process. The present application relates to an alternative and more competent method of using the basic shape parameters derived by the viewers.

GB-A-2184832 also discloses a method of detecting 'edge-breakthrough'. The specification can provide apparatus for sorting transparent objects, which give problems due to light shining through the edge zones of the objects. Areas of highly irregular re-entrants in the edge of the image are produced by edge-breakthrough, and are detected as they have a very high rate of change ~~in~~ direction of each incremental length of the edge. Edge-breakthrough zones are detected in the image and a corrected edge is provided by joining up the ends of the breakthrough zone by a smooth line.

The basic shape parameters derived may be:

Approximation of the object to a spherical shape

(blockiness)-

the area of the image is determined and this area is divided by the square of the length of the edge. Images having a high value represent a higher approximation to a spherical shape.

Symmetry in the plane of the viewers-

the centroid of each image is determined, and the image is divided into two parts along a line passing through the centroid. One part of the image is rotated through 180° to superimpose it on the other part and the mismatch area is compared with the overlap area. Images having a substantially higher overlap area than mismatch area have a high degree of mirror symmetry about said plane.

Reentrants or convex hull deviance-

re-entrants in the edge may be evaluated by comparing the length of the edge to the length of a line extending all around the edge, like an elastic band, passing straight across any re-entrants. Images having a high difference between actual edge length and 'elastic band' length are spikey. Alternatively, convex hull deviance may be measured by measuring the distance of a line extending around the edge like an elastic band and the point of the surface furthest from it.

Preferably at least four, more preferably nine viewers are used. Thus the apparatus of GB-A-2184832 can produce a set of values of blockiness, symmetry and convex hull deviance for each of the nine viewers. In addition to these 27 parameters, an additional parameter, the total count of edge-breakthroughs detected, can be derived.

The Invention

The invention provides a method of ascertaining the shape class of an object, comprising:

deriving a set of primary shape parameters representative of the shape of the object,

taking a group of two or more of the primary shape parameters to provide coordinates for deriving from a table a decision value for said group, the table for said group being fixed for all the objects;

repeating the process of deriving a decision value for other groups of two or more primary shape parameters, using a specific said table for each group; and

ascertaining from the resulting set of decision values

the shape class of the object.
The invention can improve the accuracy of classification, and can enable the number of classes to be increased.

Preferably the process of deriving decision values is repeated using groups with the same number of primary shape parameters, and preferably all the possible remaining combinations are used to obtain the maximum information.

Preferably the method is performed electronically in apparatus for sorting a succession of objects, the apparatus being substantially according to the invention of GB-A-2184832. However, the number of viewers can be reduced, and it is possible to use one viewer for sorting some objects, or two viewers, though a larger number is preferred, for instance three, four or more. the illumination is not restricted to visible light and may be for instance infra-red. The machine may just classify, e.g. providing a total of the objects in each class, or may physically separate different classes of objects.

Although the method is preferably used with a machine substantially according to the invention of GB-A-2184832, any other machine capable of measuring primary shape parameters may be used.

Preferably the primary shape parameters used comprise the maximum, minimum and average values for all the viewers of at least two basic shape parameters. Suitable basic shape parameters are blockiness, symmetry and convex hull deviance as set out in GB-A-2184832, and a satisfactory classification can be achieved on the basis of these three basic shape features, possibly also with edge break-through (see below). However, other basic shape features that can be used are for instance:

central moments;
aspect ratio;
straightness of edge measure;
convex hull deviance normalised with respect to object size;
convex hull deviance normalised with respect to arc length of missing boundary;
area of convex hull to real area;
pixel spectrum (peeling off one layer of pixels at a time);
relational functions (the relationship between the views from different viewers);
any of the foregoing extended into three dimensions.

Preferably a transformation is provided for transforming said primary shape parameters onto secondary shape parameters having a fixed range of discrete values.

Preferably the decision as to shape class is made by which decision value is most commonly identified by all the possible different tables.

The shape class decision may also be made by a hierarchical decision process.

It is preferred that said tables are generated by a training procedure in which, for each shape class, a statistically significant sample of objects falling within that class are fed through apparatus for classifying or sorting, further programmed to derive said table. However, it is not necessary to use a training procedure, and tables derived on another apparatus, or even by a computational method, may be used instead. Said groups are preferably pairs, but it is possible to form the table on the basis of groups of three or more primary shape parameters.

Description of the Preferred Embodiment

The invention will be further described by way of example and with reference to the accompanying drawings in which:

Figure 1 shows a typical frequency histogram for the

linearly transformed values of one of the primary shape parameters in the training process;

Figure 2 shows a cummulative frequency histogram for the same values in the training process;

Figure 3 shows an occurrence map table from the training process;

Figure 4 shows a table for a pair of secondary shape parameters (showing shape identifications for only some of the pairs of parameter values);

Figure 5 shows a flow chart for the shape classification process;

Figure 6 shows a decision tree for the shape class decision process.

In order to operate the method of the invention according to the preferred embodiment, three sets of fixed information will have to be provided and can be stored in the local memory of the sorting apparatus or machine :

A. A linear transformation, for transforming the values of the primary shape parameters from the sorting machine

to normalised shape parameter values.

B. A non-linear mapping of normalised shape parameter values onto secondary shape parameter values. The primary shape parameters may take any value from a continuum and this non-linear mapping maps regions of the continuum onto discrete values of secondary shape parameter. The secondary shape parameters preferably take values 0, 1, 2,... up to 15.

C. Decision value map tables (class maps).

The apparatus or sorting machine of Figure 1 of GB-A-2184832 is provided for producing electronic signals representative of shape parameters. Preferably there are nine viewers, the images from each of which are processed to give three basic shape parameters, namely blockiness, symmetry and convex hull deviance. Thus 27 signals are produced by this machine. A further signal representative of the total count of edge-breakthroughs may be provided; any view with edge-breakthrough is marked as invalid, and the signal is suppressed but the fact of edge-breakthrough is recorded; however, if all views of the object (i.e. the view from each viewer) show edge-breakthrough, the object is rejected. A microprocessor derives a smaller set of primary shape

parameters, namely the maximum, minimum and mean for all of the viewers for each of the basic shape features, except for convex hull deviance. As the minimum value of convex hull deviance is usually zero, the minimum convex hull deviance signal need not be provided, and a ninth parameter can be provided by the edge-breakthrough count.

It is preferred that the three sets of information A, B and C are derived for each sorting machine by a training procedure.

Training Procedure

The sorting machine can be set up to allow signals from the machine to be fed into a training programme which generates the sets of information A, B and C as set out above.

The information is generated by compiling results for each class of shape. A statistically-viable sample of a given shape class (say 6000 objects from the mid-range of the class and typical of that class) is fed through the machine to provide for each object the nine primary shape parameter signals as set out above. The data is stored on a computerised data storage system with each file of the storage system containing data for the many

objects of the same class. The transformation A for normalising the signals from the sorting machine is now generated. This puts the signals into a more suitable form for reading by the following part of the training procedure. For each of the primary shape parameters, the maximum value, N_{max}, and the minumum value N_{min} for all the objects of that class are taken and given the values 0 and 1023 respectively. The rest of the values N for each primary shape parameter are transformed linearly into values N′ in the range 0 to 1023 by the following relation:

$$N' = \frac{(N - N_{min}) \times 1023}{N_{max} - N_{min}} \qquad \underline{A}$$

The relation is information A referred to above, and is fed into the sorting machine.

A histogram as shown in Figure 1 is then generated showing the frequency of occurrence of each value from 0 to 1023. This histogram is then integrated to give a cummulative frequency histogram as shown in Figure 2. The range of the normalised parameters from 0 to 1023 is then divided into sixteen successive intervals, labelled 0 to 15, each interval having approximately the same number of occurrences - the labels of these intervals

are the secondary shape parameters. For a given information loss, the secondary shape parameters can be quanticized more coarsely than the primary shape parameters.

The non-linear transformation of the normalised parameter values lying in the range 0 to 1023, to the secondary shape parameters is the information B referred to above, and is fed into the sorting machine.

This process is repeated for as many classes of shape as are required for the classification or sorting being undertaken. For instance, in sorting rough diamonds, one can sort into nine classes of sawables and seven classes of makeables (sixteen classes in all), namely:

Sawables:

- octahedral perfect crystals
- octahedral imperfect crystals
- octahedral stones (ie not pure single crystals)
- long perfect crystals
- long imperfect crystals
- long stones
- irregular stones
- shaped stones
- cubes - irregular and concave (ie waisted)

Makeables:

maccles (triangular)

chips (broken)

longs (long chips)

flats

near sawables (between sawables and makeables)

cubes - rounded

cubes - geometrically perfect

There can also be three classes of rejects, namely:

misfeeds;
no vote (where the stone is of a type unrecognised by the machine);
undecided (where the stone is borderline between classes).

Data for all the classes is now compiled by drawing up shape classification occurrence maps. These may be in the form of tables as in Figure 3 in which the rows represent the values from 0 to 15 of one of the nine secondary shape parameters (for example mean value of symmetry) and the columns represent values from 0 to 15 of a second, different secondary parameter (for example mean values of blockiness). Tables of this form are generated for all of the possible different groups or combinations of two secondary shape parameters. A formula for the total number n of combinations of a

different values from a set of N values is given by:

$$n = {}_{N}C_{a} = \frac{N!}{(N - a)! \times a!}$$

In the present case there will therefore be ${}_9C_2$ combinations, that is;

$$n = 9!/2!.7! = \frac{9 \times 8}{2} = 36 \text{ tables}$$

Tables are completed by entering into each square the frequency with which the two different secondary shape parameters occurred together out of the total 6,000 objects, listed for each class. The sum of frequencies for each class across a row or down a column should be 6,000 divided by 16 ie. 375, because of the way the secondary shape parameters are derived from the primary shape parameters. There is a reading in each square of the table for each of the classes tested.

Shape classification map tables (class maps) as in Figure 4 are then generated from the occurrence map tables of Figure 3 by deriving a shape identification for each square of the table.

Class decisions for each block of the tables are based on:

$$\text{If } \left(\frac{\text{Class 1}}{\text{Class 2}} > Y_{F1}\right) \text{ then Class 1}$$

$$\text{If } \left(\frac{\text{Class 2}}{\text{Class 1}} > Y_{F2}\right) \text{ then Class 2}$$

where Y_{F1} and Y_{F2} are yield factors based on the purity of the sort required, i.e. the target error rates. The training procedure can be re-run with different target error rates, possibly several times, until a suitable sort is achieved. The shape classification space maps are stored in a computerised memory and are the information C referred to above; they are fed into the sorting machine.

Sorting

Once the machine has been trained as above or supplied with the necessary information from another source, it can be used to ascertain the shape class of an object, using the physical sorting apparatus disclosed in GB-A-2184832, in which compressed air nozzles are provided to direct an object whose shape has been determined and which is leaving the shape measuring zone to an appropriate shape bin, a rapid succession of objects being processed. A microprocessor operating according to the invention activates the compressed air

supply of the nozzles by a solenoid in order to direct the object into the bin corresponding to its shape class.

Figure 5 shows a flow chart for the shape classification process.

In operation, the object is fed through the detecting zone, and at 1 the signals from the viewers are processed to give 27 basic shape parameter readings, plus a reading representing the total number of edge-breakthroughs, which readings are in turn processed as set out above at 2 to give nine primary shape parameters a to i. These primary shape parameters a to i are then transformed at 3 by transformation A followed by transformation B to give secondary shape parameters a' to i' having values between 0 and 15. Secondary shape parameters are then taken in pairs at 4 and a shape decision value is read off from the appropriate shape classification map table at 5. Means 8 for holding all the possible shape classification map tables, are provided in the form of a RAM or computerised memory; the tables can be stored on disk. This shape decision value will just be a class identification, and it is stored in a memory at 6. The process is then repeated for all the remaining possible different combinations of two different secondary shape

parameters. Using nine primary shape parameters, a total of 36 shape decision values are produced for each object. The final shape decision, which ascertains the shape class of the object, is made at 7 and is based upon a majority vote system:

$$\text{If } \left(\frac{\text{Class } 1}{\text{Class } 2} > E_{d1}\right) \text{ then Class 1}$$

$$\text{If } \left(\frac{\text{Class } 2}{\text{Class } 1} > E_{d2}\right) \text{ then Class 2}$$

where: Ed_1 and Ed_2 are experimentally derived factors to produce the required sort characteristics. With this system there will be some 'undecided' or 'no vote' results, and one or two bins will be provided for them. These are then hand-sorted.

The operations at 1, 2, 3, 4, 5 and 7 in the flow chart above will be carried out by electronic computing elements in the form of microcomputers or (personal) computers.

If the objects are to be sorted into more than two non-reject shape classes, a decision tree, as shown in Figure 6, may be used. The secondary shape parameters are fed into a sequence of classifiers, each classifier being set up according to Figure 5 to classify the object into one of two shape class groups or into a

misfeed/no vote/undecided class. Figure 6 shows an example of a decision tree for six shape classes.

Secondary shape parameters are collected at 9 by a computing element such as a microprocessor or computer and passed to the first classifier 10. This decides whether the object belongs to a group of classes 1, 2 and 5 or to the group of classes 3, 4 and 6, or is misfed, no-vote or undecided.

If the object belongs to one of the groups of classes the information is then fed to classifier 11 or 12, according to which group of classes the object belongs to. Classifier 11 has three outputs: objects belonging to class 1 or class 2, object belonging to class 5 and undecided. Similarly, classifier 12 has the outputs: objects belonging to class 3, objects belonging to class 4 or 6 and undecided.

If the object is found to belong to class 1 or 2, or to class 4 or 6, the information is passed to classifier 13 or 14 respectively which classify the object as undecided, class 1 or class 2 in the case of classifier 13, and class 4, class 6 or undecided in the case of classifier 14.

For a stone to be assigned to class 4, the information must be passed from classifier 10 to classifier 12, and thence to classifier 14, the outputs being, in order: "class 3, 4, 6", "class 4 or 6", "class 4".

Each individual classifier has its own target error rate values (Y_F and E_d).

The foregoing description is applicable to any sorting machine with three or more viewers. With two viewers, the mean values of the primary shape parameters are not derived. With one viewer, a single primary shape parameter is produced for each of say blockiness, symmetry and convex hull deviance.

. . . .

The present invention has been described above purely by way of example, and modifications can be made within the spirit of the invention.

Claims

1. A method of ascertaining the shape class of an object, comprising:

deriving a set of primary shape parameters representative of the shape of the object,

taking a group of two or more of the primary shape parameters to provide coordinates for deriving from a table a decision value for said group, the table for said group being fixed for all the objects;

repeating the process of deriving a decision value for other groups of two or more primary shape parameters, using a specific said table for said each group; and

ascertaining from a resulting set of decision values the shape class of the object.

2. The method of Claim 1, wherein said process is repeated for groups of the same number of primary shape parameters.

3. The method of Claim 1 or 2, wherein said process is repeated for all the possible remaining groups of two or more primary shape parameters.

4. The method of any of the preceding Claims, further comprising the steps of:

feeding the object through a viewing zone;
illuminating the object as it passes through the viewing zone, using at least one viewer;

deriving from the viewer signals representative of the edges of the object as viewed at a particular instant by the viewer;

processing the signals to provide the set of primary shape parameters.

5. The method of Claim 4, wherein the viewer views substantially the whole of the profile of the object presented to the viewer.

6. The method of any of the preceding Claims, wherein a plurality of viewers spaced in one plane around the viewing zone is used, and the primary shape parameters are derived by taking the maximum, mean and minimum values of each of at least two basic shape parameters representative of the shape of the object.

7. The method of any of the preceding Claims, wherein the primary shape parameters are transformed by a mapping including a linear transformation onto a set of normalised shape parameters having values lying in a fixed range.

8. The method of Claim 7, wherein the normalised shape parameters are transformed onto secondary shape parameters taking values from a fixed set of values, by a transformation including a non-linear mapping.

9. The method of any of the preceding Claims, wherein the primary shape parameters are taken in pairs for deriving said decision value, wherein a table is provided for each pair of primary shape parameters, the rows of the table representing all the possible values of a parameter derived from one of the primary shape parameters and the columns of the table representing all the possible values of a parameter derived from the other primary shape parameter, and the spaces in the table containing a shape identification;

the values of primary shape parameters derived for the object being used to read a shape identification from the table.

10. The method of any of the preceding Claims, wherein

the shape class of the object is ascertained by a majority vote system based on the number of times each decision value is derived when the decision value deriving process is repeated for all the tables.

11. The method of any of the preceding Claims, wherein the method is used to sort the object into one of two classes, or to reject the object.

12. The method of any of the preceding Claims in which each decision value in each table comprises a vote for the object belonging to a shape class, or no vote for the object belonging to any class.

13. The method of any of the preceding Claims, wherein deriving the primary shape parameters includes the step of deriving a basic shape parameter representative of any optical edge breakthrough in the profile of the object as seen by the viewer and joining up edges on either side of the breakthrough.

14. The method of any of the preceding Claims, wherein deriving the primary shape parameters includes the step of deriving a basic shape parameter representative of the approximation of the object to a spherical shape.

15. The method of any of the preceding Claims, wherein

deriving the primary shape parameters includes the step of deriving a basic shape parameter representative of the approximation of the object to symmetry.

16. The method of any of the preceding Claims, wherein deriving the primary shape parameters includes the step of deriving a basic shape parameter representative of re-entrants in the image of the object as seen by the viewer.

17. The method of any of the preceding Claims, wherein a primary shape parameter is derived representative of the primary shape parameter representative of the total number of edge breakthroughs observed for all the viewers.

18. A classifying machine for classifying a succession of objects according to shape, comprising:

means for deriving a set of primary shape parameters representative of the shape of the object;

decision making means comprising:

means for holding decision value tables for groups of two or more of the primary shape parameters when such groups are used to provide coordinates to the respective tables;

means for providing said coordinates to respective said tables and deriving from respective said tables decision values for the respective groups; and

means for ascertaining from the resulting set of decision values the shape class of the object.

19. The classifying machine of Claim 18, wherein the decision value tables are for groups of the same number of primary shape parameters.

20. The classifying machgine of Claim 18 or 19, wherein decision value tables for all the possible groups of two or more of the primary shape parameters are held.

21. The classifying machine of any of Claims 18 to 20, further comprising:

a viewing zone through which each successive object will be fed;

means for illuminating the object as it passes through the viewing zone;

at least one electronic viewer for viewing the object as it passes through the viewing zone;

means for deriving from the viewer signals representative of the edges of the object as viewed by the viewer;

means for deriving the set of primary shape parameters representative of the shape of the object from the edge signals.

22. The classifying machine of any of Claims 18 to 21, wherein the viewer views substantially the whole of the profile of the object as presented to the viewer.

23. The classifying machine of any of Claims 18 to 22 wherein a plurality of viewers spaced around the viewing zone is used, processing means being associated with the viewers for processing the edge signals to produce a set of basic shape parameters, the set of basic shape parameters including a parameter representative of the approximation of the object to a sphere, a parameter representative of the approximation of the object to symmetry, a parameter representative of the convex hull deviance of the object and a signal representative of the number of edge breakthroughs for that view;

the primary shape parameters being the maximum, average and minimum for all the views of said basic shape

parameters of approximation to a sphere and symmetry, the maximum and average values of convex hull deviance and the total count of edge breakthroughs for all the views;

the decision meaking means comprising:

means for transforming the primary shape parameters onto normalised shape parameters having values lying in a fixed range for the machine;

means for mapping the normalised shape parameters onto a set of secondary shape parameters, taking values from a set of values defined for the machine;

said means for providing coordinates to said tables providing said secondary shape parameters in pairs;

tables for different pairs of secondary shape parameter being stored in a memory, the rows of said tables representing all the possible values of one of said pair of secondary shape parameters, the columns of the table representing all the possible values of the other of said pair of secondary shape parameters, and the spaces in the table representing a shape identification, in the form of a vote for one of two shape classes, or no vote for either;

the means for deriving decision values from said tables for the respective pairs having means to read a shape classification vote from said table using the secondary shape parameters as coordinates;

the means for ascertaining the shape class of the object comprising a memory in which all the shape class votes provided by said means for deriving decision values are stored and means for classifying the object as belonging to the first class, belonging to the second class or undecided on a majority vote basis using said shape class votes.

24. A classifying machine substantially as herein described with reference to and as shown in the accompanying drawings.

25. A method of ascertaining the shape class of an object substantially as herein described with reference to and as shown in the accompanying drawings.

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